

SUBMISSION TO GEOFISICA INTERNATIONAL

TERRANE DELETION IN SOUTHERN MEXICO

Harold R. Lang, MS 183-501, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109

Jose Antonio Barros, Department of Natural Sciences, Miami Dade Community College, Wolfson Campus, Miami, FL 33132

Enrique Cabral-Cane, Instituto de Geofisica, UNAM, Mexico

Granville Draper, Department of Geology, Florida International University, Miami, FL 33199

Christopher G.A. Harrison, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149

Pamela E. Jansma, Department of Geology, University of Puerto Rico, Mayaguez, Puerto Rico 00681

Christopher A. Johnson, EXXON Production Research Company, Houston, TX 77210

ABSTRACT

The tectonostratigraphic evolution of the southern margin of the North America Plate in Mexico is still in debate. Recent explanations rely on Laramide (Campanian-Eocene) accretion of far-travelled oceanic terranes. Here we report new mapping results from a 30 km x 250 km transect of northern Guerrero State, from Huetamo, Michoacan, to Papalutla, Guerrero. Our objectives were to evaluate proposed terrane boundaries and assess tectonostratigraphic evolution of the transect.

Published mapping shows that the distribution of exposures of Grenville-age continental basement, mid-Cretaceous rudist reef carbonates and associated facies, a Laramide fold and thrust belt, and post-Laramide basin and range extensional structures link Mexico north and south of the Mexican Volcanic Belt. No Mesozoic melange, blueschist or ophiolite sequence exist. Gravity modelling shows that the crust is continental and paleomagnetic measurements require paleogeographic coherence.

Our map, structural cross section and assessment of the 9 km thick stratigraphic section are consistent with the above regional information. The area was the site of a Jurassic-Early Cretaceous back-arc basin, filled with andesitic, submarine volcanics and sedimentary rocks, and formed on Late Permian-Early Triassic continental basement. Aptian/

Albian transgression resulted in deposition of mid-Cretaceous platform and basinal facies on the western margin of the Tethys realm. The platform was drowned by Late Cretaceous flysch sedimentation. Late Cretaceous-Paleogene Laramide orogenesis resulted in approximately 60 km shortening due to NE E-vergent folding and thrust faulting. Tertiary postorogenic extension led to terrestrial volcanism, fluvial siliciclastic sedimentation, and formation of a prominent, N-trending graben with 3 km of structural relief.

No stratigraphic incompatibilities suggesting terrane accretion exist. The proposed Arcelia/Teloloapan subterrane boundary is a normal fault on the eastern edge of a Tertiary graben, the Guerrero/Mixteco terrane boundary is a normal contact between flysch and platform strata on a Laramide fold limb; and the Guerrero/Mixteca and Nahuatl/Mixteco terrane boundaries are Laramide thrust faults. These terranes and subterrane should therefore be deleted.

KEY WORDS: Terranes, Northern Guerrero State, Geologic Mapping, Stratigraphy, Structure, Southern Mexico

INTRODUCTION

THE SOUTHERN MEXICO PROBLEM

In the first modern plate reconstruction of Pangaea, Bullard et al. (1965) considered southern Mexico an anomaly because of the apparent overlap of Mexico and South America. Attempts to explain this overlap led to numerous *ad hoc* hypotheses, including: (1) "arbitrary rotation" (e.g., Dietz and Holden, 1970, p. 4944) of most of southern Mexico into the Gulf of Mexico or elsewhere prior to Jurassic time; and (2) the proposition that "megashears" isolated most of Mexico from the rest of North America during various stages of the evolution of the Caribbean eastern Pacific and North America plates (e.g., Coney, 1978; Silver and Anderson, 1983; Burke, 1988; Gastil, 1991). To these, Campa and Coney (1983) added the suspect terrane hypothesis (Figure 1A) which itself has been subjected to numerous revisions, most recently by Sedlock et al. (1993) (Figure 1 B). According to Campa and Coney (1983), terranes of southern and western Mexico were accreted in Campanian-Eocene time, during the Laramide Orogeny. But some recent plate reconstructions (e.g., Stockhert et al., 1995, Figure 3) show no overlap problem and no terrane accretion in Mexico since Early Cretaceous time. Thus, the tectonostratigraphic evolution of the southwestern margin of the North America plate in Mexico

is still uncertain.

PURPOSE

in 1989, we began an effort to bring new data to this debate through field mapping along a geological transect in southwestern Mexico (Figures 1 and 2). Monod et al. (1994) suggested that this type of work is critically needed for determining the tectonostratigraphic evolution of southern Mexico. Here we summarize the major results that led to our main conclusion: there are no stratigraphic or structural problems in the region that require the existence of accreted terranes.

Our work in Mexico started as a feasibility study to test the applicability of methods developed in Wyoming for basin analysis aided by remote sensing (Lang et al., 1987 and Lang and Paylor, 1994) to the less well known southern Mexico region. Success of the feasibility study (e.g., Barros et al., 1989; Johnson et al., 1991; Jansma et al., 1991; Johnson et al., 1992) led to a major field mapping effort that incorporated use of Landsat Thematic Mapper data (Lang and Cabral-Cane, 1993). The objective was to characterize proposed terrane boundaries and assess the tectonostratigraphic evolution of a region covered by a 30 km X 250 km geological transect of northern Guerrero State (Figure 3).

RESULTS

GEOLOGICAL SETTING

The line of transect was selected to cross the Guerrero-Mixteca terrane boundary (Figure 1). Running from Huetamo, Michoacan, to Papalutla, Guerrero, the transect is located south of the Mexican Volcanic Belt, an east-west trending belt of Neogene-Recent volcanic rocks that form a topographic plateau across Mexico. Review of published descriptions of the basic regional stratigraphic framework for this part of Mexico (Figure 2) shows that:

- (1) Grenville-age (1 100 Ma), anorthosite and gneiss, continental basement is exposed in a belt from north of Puerto Angel to west of Oaxaca and northward in isolated exposures to southeast of Xilitla, cropping out beneath volcanics of the Mexican Volcanic Belt (Ortega-Gutierrez, 1981; Ortega-Gutierrez et al., 1992; Suter, 1987);
- (2) Basement is overlain by rocks that range in age from Paleozoic (high grade metamorphic exposed near Acatlan) to Jurassic and Early Cretaceous rocks that include low grade metamorphic as well as unmetamorphosed continental and marine strata (Yanez et al., 1991 ; Ortega-Gutierrez et al., 1992);
- (3) The region was blanketed by mid-Cretaceous marine carbonates, now exposed as erosional remnants of rudist reef, bank, platform and

basin deposits, that formed the western margin of the Albian Tethys realm (Alencaster, 1984; Jenkyns, 1991; Enos, 1983). These primarily Albian strata provide an important stratigraphic marker;

- (4) During Late Cretaceous through Eocene time, east-west shortening resulted in fold and thrust deformation in the Sierra Madre Oriental that was cinematically and temporally similar to Laramide orogenesis in the U.S. Cordillera to the north (Suter, 1984 and 1987; Enos, 1983). This fold and thrust belt extends into southern Mexico (Campa, 1985);
- (5) Tertiary rocks are primarily terrestrial elastics, volcanoclastics and volcanics except for a belt of marine elastics along the Gulf coast margin and one remnant on the Pacific margin near Playa Azul (Ortega-Gutierrez et al., 1992; Henry and Aranda-Gomez, 1992);
- (6) Cretaceous to Paleogene granitic batholiths intrude older rocks in a belt along the Pacific coastal margin (Ortega et al., 1992; Schaaf, 1991; Schaaf et al., 1995; Moran-Zenteno, 1992);
- (7) The youngest structures are primarily extensional and include ubiquitous normal faults and grabens (Ortega-Gutierrez et al., 1992; Henry and Aranda-Gomez, 1992);
- (8) No Mesozoic melange, blueschist or ophiolite sequence has been reported anywhere in the region covered by Figure 2, although

Mesozoic marine volcanics (primarily pillow andesites and rare basalts) have been considered “ophiolite sequences” despite the lack of the other diagnostic lithologies (e. g., Centeno-Garcia et al., 1993a; and Talavera-Mendoza et al., 1995).

Paleomagnetic data show that the region has maintained its present relative position with respect to the rest of North America and has not experienced major internal displacements since at least Early Cretaceous time (Guerrero et al., 1990; Bohnel et al., 1989; and Bohnel and Negendank, 1988). Lack of published borehole or seismic reflection data south of the Mexican Volcanic Belt has hindered determination of deep crustal structure, but gravity modelling shows that the crust is approximately 40 km thick with a density structure showing continental affinity (Garcia-Perez, 1995; Urrutia-Fucugauchi and Molina, 1992; and Arzate et al., 1993),

STRATIGRAPHY

As depicted on Figures 3 and 4, our mapping fits well with the regional geology described above. The total exposed section is approximately 9 km thick. Strata were assigned to formations using the lithostratigraphic nomenclature of Pantoja-Alor (1959) and Fries (1960), with revisions suggested by Ontiveros-Tarango (1973) and us (Johnson et al., 1991; Jansma et al., 1991; Jansma and Lang, 1995; Cabral-Cane, 1995;

Barros, 1995).

The two lowest lithostratigraphic units form a predominantly chlorite grade metamorphic sequence composed of: (1) the Taxco Schist which contains pre-Jurassic(?) phyllitic metapelites and metatuffs overlain unconformably by (2) the Rota Verde ("greenstone") Taxco Viejo and equivalents which contain Jurassic-Early Cretaceous graywackes, metandesites and rare metabasalts of marine (pillows) and terrestrial (breccias and agglomerates) origin, phyllites and interbedded cherts, and graded sandstones/conglomerates of probable marine turbidite origin. The base of the Taxco Schist is not exposed along our traverse, but according to Elias-Herrera and Sanchez-Zavala (1990) this unit is approximately 1.5 km thick near Zacazonapan (Figure 2), where it rests unconformably on Late Permian-Early Triassic granitic basement of continental affinity.

Unconformably above these units is the Morelos Formation and equivalent strata: primarily Albian, massive- to medium-bedded rudist limestones and dolostones of reef, platform, bank and backreef origin that grade into thin-bedded dark, limestones, shales (locally phyllitic), and chert of basin origin. Late Cretaceous marine shales and sandstones of the Mexcala Formation constitute a flysch sequence in conformable, but sharp, contact with Morelos strata. In the eastern area of the transect (F, Figure 4), a large body of Maastrichtian sandstone and conglomerate of

littoral, deltaic, paludal and fluvial origin exists within the Mexcala Formation (Tilton et al., 1993).

The Cretaceous marine sequence is covered unconformably by Paleogene and younger terrestrial rocks. At the base are well-indurated, fluvial redbed conglomerates and sandstones and volcanoclastic sandstones/siltstones assigned to the Balsas Formation. These rocks are overlain unconformably by undifferentiated tuffs, flows, pyroclastic rocks and associated dikes, plugs and larger hypabyssal bodies. These volcanic rocks exhibit variable, but predominantly rhyolitic compositions. Poorly-indurated, fluvial volcanoclastic sandstones and conglomerates are interbedded with the volcanics locally. Gypsiferous beds also occur in the Tertiary sequence.

STRUCTURE

At 1:50,000 scale, fold axes and faults generally strike NW-SE, ranging through N-S to NE-SW. Deformation of lower Balsas and older strata resulted in an east-verging fold and thrust belt with local backthrusts such as those west of Iguala and at Papalutla (Figure 3A). We determined an average transport direction to the NEE, based on structural measurements at outcrops (Cabral-Cano, 1995; Barros, 1995; Johnson, 1990). Restoration of the Figure 3B cross section suggests E-W shorten-

ing of approximately 60 km, or about 20%, due to folding and thrust faulting. This transport direction and percentage shortening are nearly identical to those reported by Suter (1987) in the Xilitla region of the Sierra Madre Oriental (Figure 2),

Along the transect, fold and thrust belt structures are unconformably covered by the less-deformed upper Balsas volcaniclastic and undifferentiated volcanic rocks. Related hypabyssal bodies intrude all older strata. Ubiquitous normal faults cut the entire stratigraphic sequence. A prominent graben that we discovered between Ciudad Altamirano and Arcelia records extension associated with the normal faulting (Jansma and Lang, 1995). We estimate post-Morelos subsidence associated with this graben structure to be approximately 3 km.

We consider the fold and thrust belt to be the southern extension of the well-documented Laramide belt of the Sierra Madre Oriental. Subsequent normal faulting and graben development exhibit similar geometry to basin and range structures that affected much of western Mexico and the US southwest since Neogene time (Suter, 1991; Henry and Aranda-Gomez, 1992) (Figure 2).

DISCUSSION

Our mapping shows that proposed terrane boundaries (Figures 1 and

3B) coincide with normal faults, normal stratigraphic contacts, or thrust faults, No stratigraphic incompatibilities that would suggest juxtaposition of far-travelled terranes exist across any of the boundaries (Figure 3B and 4). Modelling of gravity data agrees with our Figure 3B structural interpretation (Garcia-Perez, 1995). We suggest an alternative model for the tectonostratigraphic evolution of the region more consistent with the results of our stratigraphic and structural observations.

A Jurassic back-arc basin existed along the western margin of the region covered by Figure 2. Its exact configuration is poorly constrained because of poor exposure due to more recent truncation, uplift, erosion and/or cover along the continental margin of western Mexico (Schaaf et al., 1995). The basin formed on the continental basement exposed today near Zacazonapan and between Puerto Angel and Xilitla. This back-arc basin was the southern extension of a more extensive basin system along the entire length of western Mexico during Late Jurassic/Early Cretaceous time. The basin filled with siliciclastic sediments, chert and volcanics, which were subjected to seafloor metamorphism (Talavera-Mendoza et al., 1995), through Early Cretaceous time. Mid- Cretaceous transgression resulted in widespread development of rudist platforms and associated carbonate facies, locally and throughout much of Mexico, on the western margin of the Tethys realm. Laramide (Cenomanian-Mid Eocene) deforma-

tion resulted in:

- (1) Generally eastward but locally westward, depending on local relief, marine regression;
- (2) Incipient metamorphism of pre-Morelos strata as well as Morelos basinal equivalents, associated with Late Cretaceous uplift;
- (3) East verging thrust faulting and folding;
- (4) Paleogene synorogenic redbed deposition.

Cessation of Laramide deformation was followed by Late Eocene-Neogene extension, normal faulting, volcanism, hypabyssal intrusion and local hydrothermal alteration of older rocks.

This assessment is consistent with Alencaster's (1984) analysis of the biostratigraphic record, Cserna et al.'s (1978) and Enos' (1983) tectonostratigraphic models, Stockhert et al.'s (1995) plate reconstruction of the North America-Caribbean-South America region, and Cserna's (1976) evaluation of tectonostratigraphic controls on the distribution of mineral deposits in Mexico.

CONCLUSION

Our mapping and tectonostratigraphic assessment of the Guerrero transect shows that boundaries of the Guerrero/Mixteca, Guerrero/Mixteco, and Nahuatl/Mixteco terranes and the Arcelia/Teloloapan

subterranees are normal stratigraphic contacts or faults. Across these boundaries we found no major stratigraphic discontinuities. Paleomagnetic studies and crustal gravity models also do not indicate that separate terranes and their boundaries exist in the area. These proposed terranes and subterranees should therefore be deleted.

ACKNOWLEDGMENTS

This paper presents the results of research conducted as part of the Multispectral Analysis of Southwest Mexico Project and carried out at Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Additional support for PEJ was provided by NASA grants NGT-40053 and NCCW-56 and NSF grant HRD-93-53549 to the University of Puerto Rico; and for JAB, EC-C, CAJ and CGAH by NASA grants NAGW-1 678 and NAGW-271 O to the University of Miami. EC-C received support for field work from The Gulf Coast Association of Geological Societies Student Aid Program and The Geological Society of America student research grant program, as well as a Ph. D. fellowship from the Direccion General de Asuntos del Personal Academico (UNAM). GD received additional support from the Latin-American Caribbean Center of Florida International University. The project benefited from logistic support in the field provided by Dr. Jaime Urrutia-Fucugauchi from the Instituto de Geofisica

(UNAM). Mike Abrams' review of an earlier version of this paper was most helpful.

REFERENCES CITED

- Alencaster, G., 1984, Late Jurassic-Cretaceous molluscan paleogeography of the southern half of Mexico, in G.E.G. Westermann (Ed.), *Jurassic-Cretaceous Biochronology and Paleogeography of North America: Geological Assoc. Canada, Special Paper 27*, p. 77-88.
- Arzate, J. A., M. Mareschal, and J. Urrutia-Fucugauchi, 1993, A preliminary crustal model of the Oaxaca continental margin and subduction zone from magnetotelluric and gravity measurements, *Geof.Int.*, v. 32, p. 441-452.
- Barros, J. A., 1995, *Geology and tectonic evolution of the Taxco District: University of Miami, Miami, Florida, unpub. PhD Thesis*, 130 pp.
- Barros, J. A., H. Lang, C. Johnson, and C.G.A. Harrison, 1989, Thrust tectonics and Laramide deformation in Taxco, *GSA Abstracts with Programs*, p. A91.
- Bohnel, H., and J.F.W. Negendank, 1988, Paleomagnetism of Puerto Vallarta intrusive complex and the accretion of the Guerrero terrane, Mexico, *Physics of the Earth and Planetary Interiors*, v. 52, p. 330-338.
- Bohnel, H., L. Alva-Valdivia, S. Gonzales-Huesca, J. Urrutia-Fucugauchi, and D.J. Moran-Zenteno, 1989, Paleomagnetic data and the accretion of the Guerrero terrane, southern Mexico continental margin, in J.W. Hillhouse (Ed.), *Deep Structure and Past Kinematics of Accreted Terranes*, AGU

- Geophysical Monograph 50, IUGG v. 5, p. 73-92.
- Bullard, E. C., J.E. Everett, and A.G. Smith, 1965, The fit of the continents around the Atlantic, Phil. Trans. Roy. Soc. London, A258, p. 41-51.
- Burke, K., 1988, Tectonic evolution of the Caribbean, Ann. Rev. Earth Planet. Sci., v. 16, p. 201-230.
- Cabral-Cane, E., 1995, Tectonostratigraphic assessment of the Tierra Caliente metamorphic complex, southern Mexico, University of Miami, Miami, Florida, unpub. PhD Thesis, 166 pp.
- Campa, M. F., 1985, The Mexican thrust belt, in D.G. Howell (Ed.), Tectonostratigraphic Terranes of the Circum-Pacific region: Circum-Pacific Council for Energy and Mineral Resources, p. 299-313.
- Campa, M. F., and P.J. Coney, 1983, Tectonostratigraphic terranes and mineral resources distribution in Mexico, Can. J. Earth Sci., v. 20, p. 1040-1051.
- Campa, M. F., J. Ramirez, R. Flores, and P.J. Coney, 1981, Terrenos tectonostratigraficos de la Sierra Madre del Sur, region comprendida entre los estados de Guerrero, Michoacan, Mexico y Morelos, Universidad Autonoma de Guerrero, Serie Tecnico Cientifica, No. 10, 26 pp.
- Centeno-Garcia, E., J.L. Garcia, M. Guerrero-Suastegui, J. Ramirez-Espinosa, J.C. Salinas-Prieto, and O. Talavera-Mendoza, 1993a, Geology of the southern part of the Guerrero terrane, Ciudad Altamirano-Teloloapan

- area, in F. Ortega-Gutierrez, et al. (Eds.) Guidebook of Field Trip B, First Circum-Pacific and Circum-Atlantic Terrane Conference, UNAM, Instituto de Geologia, p. 23-33.
- Centeno-Garcia, E., J. Ruiz, P.J. Coney, P.J. Planchett, and F. Ortega-Gutierrez, 1993b, Guerrero terrane of Mexico: its role in the southern Cordillera from new geochemical data: *Geology*, v. 21, p. 419-422.
- Coney, P. J., 1978, Mesozoic-Cenozoic Cordilleran plate tectonics, GSA, Memoir 152, p. 33-50.
- Cserna, Z. de, 1976, Mexico - geotectonics and mineral deposits: New Mexico Geological Society, Special Publication No. 6, p. 18-25.
- Cserna, Z. de, M. Palacios-Nieto, and J. Pantoja-Alor, 1978, Relaciones de facies de las rotas Cretácicas en el noroeste de Guerrero y en áreas colindantes de México y Michoacán: *Revista del Instituto de Geología de la UNAM*, v. 2, p. 8-18.
- Dietz, R. S. and J. C. Holden, 1970, Reconstruction of Pangaea: Breakup and dispersion of continents, Permian to present, *J. Geophys. Res.*, v. 75, p. 4939-4956.
- Elias-Herrera, M., and J. Sanchez-Zavala, J., 1990, Tectonic implications of mylonitic granite in the lower structural levels of the Tierra Caliente Complex (Guerrero State, southern Mexico), UNAM, *Rev. Ins. Geol.*, v. 9, p. 113-125.

- Enos, P., 1983, Late Mesozoic paleogeography of Mexico, in M.W. Reynolds and E.D. Dolly (Eds.), Mesozoic Paleogeography of West-Central United States: Rocky Mountain Section SE PM, p. 133-157.
- Fries, C., 1960, Geologia del Estado de Morelos y de partes adyacentes de Mexico y Guerrero, region central meridional de Mexico, UNAM, Instituto de Geologia, Bul. 60, 235 pp.
- Garcia-Perez, F., 1995, Caracterizacion geofisica de la region Tierra Caliente y areas colindantes, Estados de Guerrero, Mexico y Morelos: University of Mexico, Institute of Geophysics, Mexico City, Mexico, Unpub. MS thesis, 55 pp.
- Gastil, G., 1991, Is there a Oaxaca-California megashear? Conflict between paleomagnetic and other elements of geology, Geology, v. 19, p. 502-505.
- Guerrero, J. C., E. Herrero-Bervera, and C.E. Helsley, 1990, Paleomagnetic evidence for post-Jurassic stability of southeastern Mexico: Maya terrane, J. Geophys. Res., v. 95, 65, p. 7091-7100.
- Henry, C. D., and J.J. Aranda-Gomez, 1992, The real southern Basin and Range: Mid- to late Cenozoic extension in Mexico, Geology, v. 20, p. 701-704.
- INEGI, 1985a, Carta Geologica, 1:250,000, Hoja E14-5, Cuernavaca, Mexico, Direccion General de Geografia, Mexico DF.

INEGI, 1985b, Carta Geologica, 1:250,000, Hoja E14-4, Ciudad Altamirano, Mexico, Direccion General de Geografia, Mexico, DF.

Jansma, P. E., and H. R. Lang, 1995, Application of spectral stratigraphy to Upper Cretaceous and Tertiary rocks in southern Mexico: Tertiary graben control on volcanism, Photogrammetric Engineering and Remote Sensing (in press).

Jansma, P. E., H.R. Lang, and C.A. Johnson, 1991, Preliminary investigation of the Tertiary Balsas Group, Mesa Los Caballos area, northern Guerrero state, Mexico using Landsat Thematic Mapper data, The Mountain Geologist, v. 28, p. 137-150.

Jenkyns, H.C., 1991, Impact of Cretaceous sea level rise and anoxic events on the Mesozoic carbonate platform of Yugoslavia, AAPG Bull., v. 75, p. 1007-1017.

Johnson, C. A., 1990, Stratigraphy and structure of the San Lucas area, Michoacan and Guerrero states, southwestern Mexico, University of Miami, Miami, Florida, Unpub. PhD Thesis, 220 pp.

Johnson, C. A., H.R. Lang, E. Cabral, C.G.A. Harrison, and J.A. Barros, 1991, Preliminary assessment of stratigraphy and structure, San Lucas region, Michoacan and Guerrero states, southwest Mexico, The Mountain Geologist, v. 28, p. 121-136.

Johnson, C. A., H. Lang, E. Cabral-Cane, C. Harrison, and J. Barros, 1992,

Preliminary assessment of stratigraphy and structure, San Lucas region, Michoacan and Guerrero States, SW Mexico: Reply, *The Mountain Geologist*, v. 29, p. 3-4.

Lang, H. R., S.L. Adams, J.E. Conel, B.A. McGuffie, E.D. Paylor, and R.E. Walker, 1987, Multispectral remote sensing as stratigraphic and structural tool, Wind River basin and Bighorn basin area, Wyoming, *AAPG Bull.*, v. 71, p. 389-402.

Lang, H.R. and E. Cabral-Cane, 1993, Progress report - multi spectral analysis of the stratigraphic/structural record, SW Mexico Project, in F. Ortega-G utierrez, et al. (Eds.), *First Circum-Pacific and Circum-Atlantic Terrane Conference Proceedings*, Universidad Nacional Autonoma de Mexico, Instituto de Geologia, p. 76-77.

Lang, H.R. and E.D. Paylor, 1994, Spectral stratigraphy: remote sensing lithostratigraphic procedures for basin analysis, central Wyoming examples: *Journal of Nonrenewable Resources*, Oxford Press, v. 3, p. 25-45.

Monod, O., M. Faure, and D. Thieblemont, 1994, Guerrero terrane of Mexico: its role in the southern Cordillera from new geochemical data Comment: *Geology*, v.22, n. 5, p. 477,

Moran-Zenteno, D., 1992, Investigaciones isotopicas de Rb-Sr y Sm-Nd en rotas cristalinas de la region de Tierra Colorada-Acapulco-Cruz

- Grande, Estado de Guerrero, Universidad National Autonoma de Mexico, Unpub. Tesis de Doctorado, 187 pp.
- Ontiveros-Tarango, G., 1973, Estudio estratigrafico de la portion noroccidental de la cuenca Morelos-Guerrero, Assoc. Mex.Geol. Petrol., Bul. 25 (4-6), p. 190-234,
- Ortega-Gutierrez, F., 1981, Metamorphic belts of southern Mexico and their tectonic significance, Geof.Int., v. 20-3, p. 177-202.
- Ortega-Gutierrez F., et al., 1992, Carta geologica de la Republics Mexicana (5th edition): Consejo De Recursos Minerales, Mexico, 1:2,000,000 scale map and explanatory text, 74 pp.
- Pantoja-Alor, J., 1959, Estudio geologico de reconocimiento de la region de Huetamo, Estado de Michoacan: Cons, Recursos Nat. No. Renovables (Mexico), Bul. 50, 36 pp.
- Schaaf, P., 1991, Isotopengeochemische Untersuchungen an granitoiden Gesteinen eines aktiven Kontinentalrandes: Alter und Herkunft der Tiefengesteinskomplexe an der Pazifikkueste: Alter und Herkunft der Tiefengesteinskomplexe an der Pazifikkuste Mexikos zwischen Puerta Vallarta und Acapulco: Unpub.Diss. Univ. Munchen, 202 pp.
- Schaaf, P., D.Moran-Zenteno, M. S. Hernandez-Bernal, G. Solis-Pichardo, G. Tolson, and H. Kohler, 1995, Paleogene continental margin truncation in southwestern Mexico: Geochronological evidence, Tectonophysics, in

press.

Sedlock, R. L., F. Ortega-Gutierrez, and R.C. Speed, 1993, Tectonostratigraphic terranes and tectonic evolution of Mexico, GSA Special Paper **278**, 153 pp.

Silver, L.T. and T. H. Anderson, 1983, Further evidence and analysis of the role of the Mojave-Sonora megashear(s) in Mesozoic Cordilleran tectonics: GSA Abstracts with Programs, v. 15, p. 273.

Stockhert, B., W.V. Maresch, M. Brix, C. Kaiser, A. Toetz, R. Kluge, and G. Kruckhans-Lueder, 1995, Crustal history of Margarita Island (Venezuela) in detail: constraint on the Caribbean plate-tectonic scenario, *Geology*, v. 23, p. 787-790.

Suter, M., 1984, Cordilleran deformation along the eastern edge of the Vanes-San Luis Potosi carbonate platform, Sierra Madre Oriental fold-thrust belt, east-central Mexico, *GSA Bull.*, v. 95, p. 1387-1397.

Suter, M., 1987, Structural traverse across the Sierra Madre Oriental fold-thrust belt in east-central Mexico, *GSA Bull.*, v. 98, p. 249-264.

Suter, M., 1991, State of stress and active deformation in Mexico and western Central America, in D.B. Slemmons et al. (Eds.), *Neotectonics of North America: GSA Decade Map Volume*, p. 401-421.

Talavera-Mendoza, O., J. Ramirez-Espinosa, and M. Guerrero-Suastegui, 1995, Petrology and geochemistry of the Teloloapan subterranean: A

Lower Cretaceous evolved intra-oceanic island arc: *Geofisica International*, v. 34, no. 1, p. 3-22.

Tilton, T. L., H.R. Lang, I. Ferrusquia-Villafraña, J.G. Pittman, and M. Lockley, 1993, Dinosaur footprints in the Mexcala Formation, central Mixteco terrane, State of Puebla, Mexico, in F. Ortega-Gutierrez, et al. (Eds.), *First Circum-Pacific and Circum-Atlantic Terrane Conference Proceedings*: UNAM, Inst. de Geologia, p. 153.

Urrutia-Fucugauchi, J., and R.S. Molina, 1992, Gravity modelling of regional crustal and upper mantle structure of the Guerrero terrane - 1. Colima graben and southern Sierra Madre Occidental, western Mexico, *Geof. Int.*, v. 31, p. 493-507.

Yanez, P., J. Ruiz, P.J. Patchett, F. Ortega-Gutierrez, and G.E. Gehrels, 1991, Isotopic studies of the Acatlan complex, southern Mexico: Implications for Paleozoic North American tectonics: *GSA Bull.*, v. 103, p. 817-828.

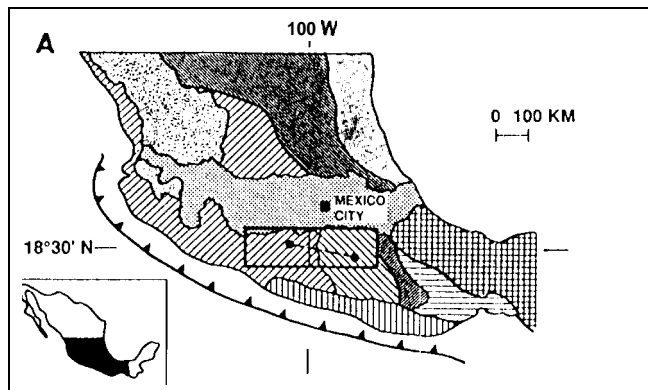
FIGURE 1. Comparison of two different terrane interpretations of central and southern Mexico. A. map of “suspect” terranes (after Campa and Coney, 1983). B. map of “tectonostratigraphic” terranes (after Sedlock et al., 1993). The Sierra Madre (A) and Guachichi (B) terranes coincide with the Laramide Sierra Madre Oriental fold and thrust belt. Also identified are: the trace of the Acapulco-Mid America trench (bold line with teeth) which marks the southern edge of the North America plate; the areas covered by the Ciudad Altamirano (west rectangle, INEGI, 1985a) and Cuernavaca (east rectangle, INEGI, 1985b) 1:250,000 scale geologic map sheets (18-1 9°N; 98-102°W); and the line of transect mapped in this study.

FIGURE 2. Simplified geologic map of central and southern Mexico, compiled from published mapping, including Ortega-Gutierrez et al. (1992), INEGI (1985a and 1985 b), Henry and Aranda-Gomez (1992), and Suter (1987), plus our own mapping. Compare geology to terrane maps in Figure 1. Area mapped in the Guerrero transect is outlined. Selected cities and villages are identified; PV: Puerto Vallarta, TP: Tepee, MA: Manzanillo, C: Colima, GU: Guadalajara, PA: Playa Azul, AR: Arteaga, AG: Aguascalientes, AP: Arperos, G: Guanajuato, H: Huetamo, PO: Placeres del Oro, Z: Zihuatanejo, CA: Ciudad Altamirano, AL: Arcelia, ZA: Zacazonapan, TJ:

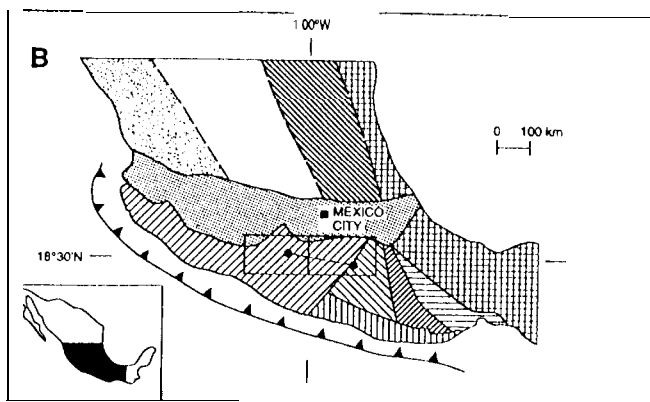
Tejupilco, TE: Teloloapan, A: Acapulco, I: Iguala, IS: Ixtapan de la Sal, P: Papalutla, M (dot): Mitepec, TI: Ticuman, CU: Cuernavaca, M (box): Mexico City, X: Xilitla, AC: Acatlan, PG: Puerto Angel, O: Oaxaca, V: Veracruz.

FIGURE 3. Geology of the Guerrero transect (for location see Figure 2). A. Geological map (for lithostratigraphic nomenclature see Figure 4). B. East-West geological cross section (no vertical exaggeration). Dashed horizon in the blue unit identifies the contact between the Cuautla Formation and the Morelos Formation in the eastern part of the cross section. Dot pattern in the green unit (Mexcala Formation) identifies major sandstone bodies in this flysch sequence. Surface locations of selected, purported terrane boundaries are identified by numbered red lines. From west to east, these are: (1) the Arcelia/Teloloapan subterrane boundary of Campa et al. (1981), Centeno-Garcia et al. (1993a and 1993b) and Talavera-Mendoza et al. (1995); (2) the Guerrero/Mixteco terrane boundary of Centeno Garcia et al. (1993a and 1993b) and Talavera-Mendoza et al. (1995); (3) the Guerrero/Mixteca terrane boundary of Campa et al. (1981) and Campa and Coney (1983), and (4) the Nahuatl/Mixteco terrane boundary of Sedlock et al. (1993). The change in spelling from "Mixteca" to "Mixteco" was presumably made for Spanish grammatical reasons: adjective (*mixteco*) - noun (*terreno*) gender agreement.

FIGURE 4. Panel diagram, hung on base of Morelos Formation and equivalents (Aptian/Albian), depicting stratigraphic relationships and lithostratigraphic nomenclature that we adopted for mapping the Guerrero transect. Colors correspond to those used in Figure 3; lithologies are described in the text. As cited on the Figure 3A caption, terrane boundaries have been proposed between A and C, D and E, and E and F. A is after Johnson et al., 1991; B, Jansma et al., 1991, and Jansma and Lang, 1995; C and D, Cabral-Cane, 1995; and E, Barros, 1995. Here we report F for the first time,



- | | |
|-------------------------|---------|
| GUERRERO | MIXTECA |
| SIERRA MADRE OCCIDENTAL | OAXACA |
| MEXICAN VOLCANIC BELT | XOLAPA |
| SIERRA MADRE | JUAREZ |
| COAHUILA | MAYA |



- | | |
|-----------------------|-----------|
| NAHUATL | MIXTECO |
| TAHUE | ZAPOTECO |
| MEXICAN VOLCANIC BELT | CHATINO |
| GUACHICHIL | CUICATECO |
| TEPEHUANO | MAYA |

FIG 1
Lang et al.

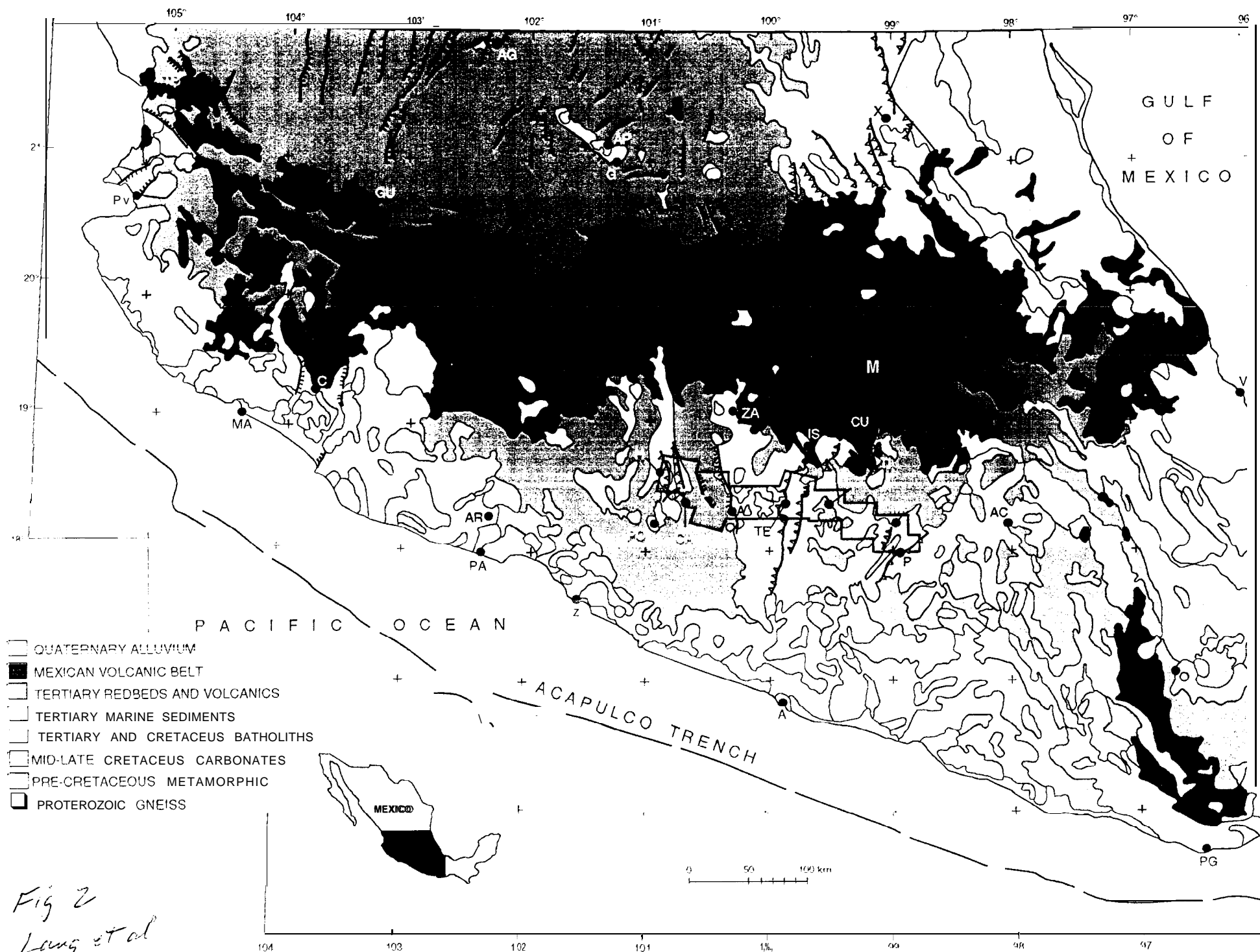
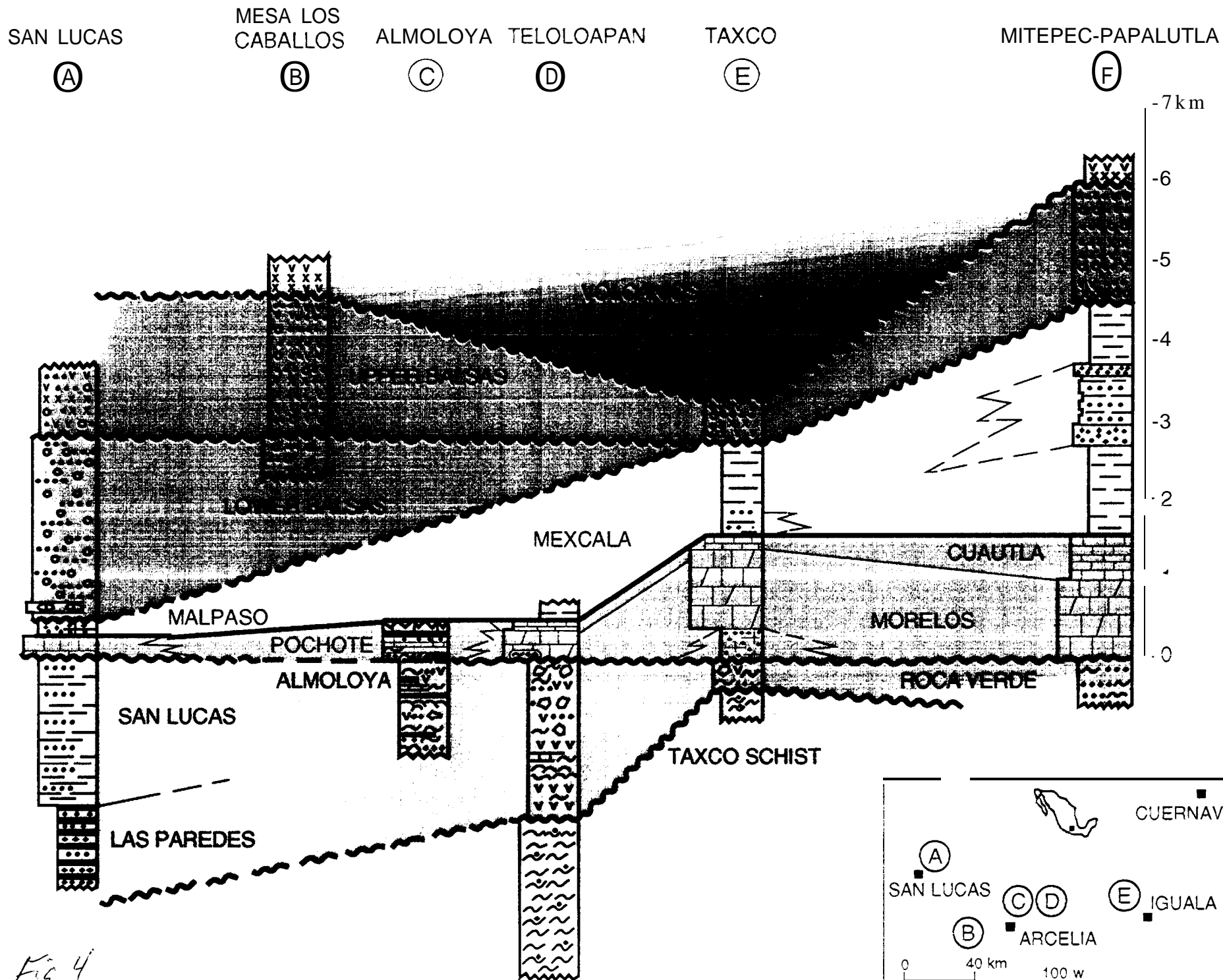


Fig 2
Long et al



- VILLAGE
- v VUELTA DEL RIO
- SP SAN MARTIN PACHIVIA
- c CHILACACHAPA
- M MITEPEC
- P PAPALUTLA
- WATER RESERVOIR
- ▲ THRUST/REVERSE FAULT (TEETH ON UPPER PLATE)
- ▤ NORMAL FAULT (BARBS ON DOWN BLOCK)
- DIKE, JOINT SYSTEM, NEAR VERTICAL FAULT, LINEAMENT
- ⊞ SLUMP/LANDSLIDE

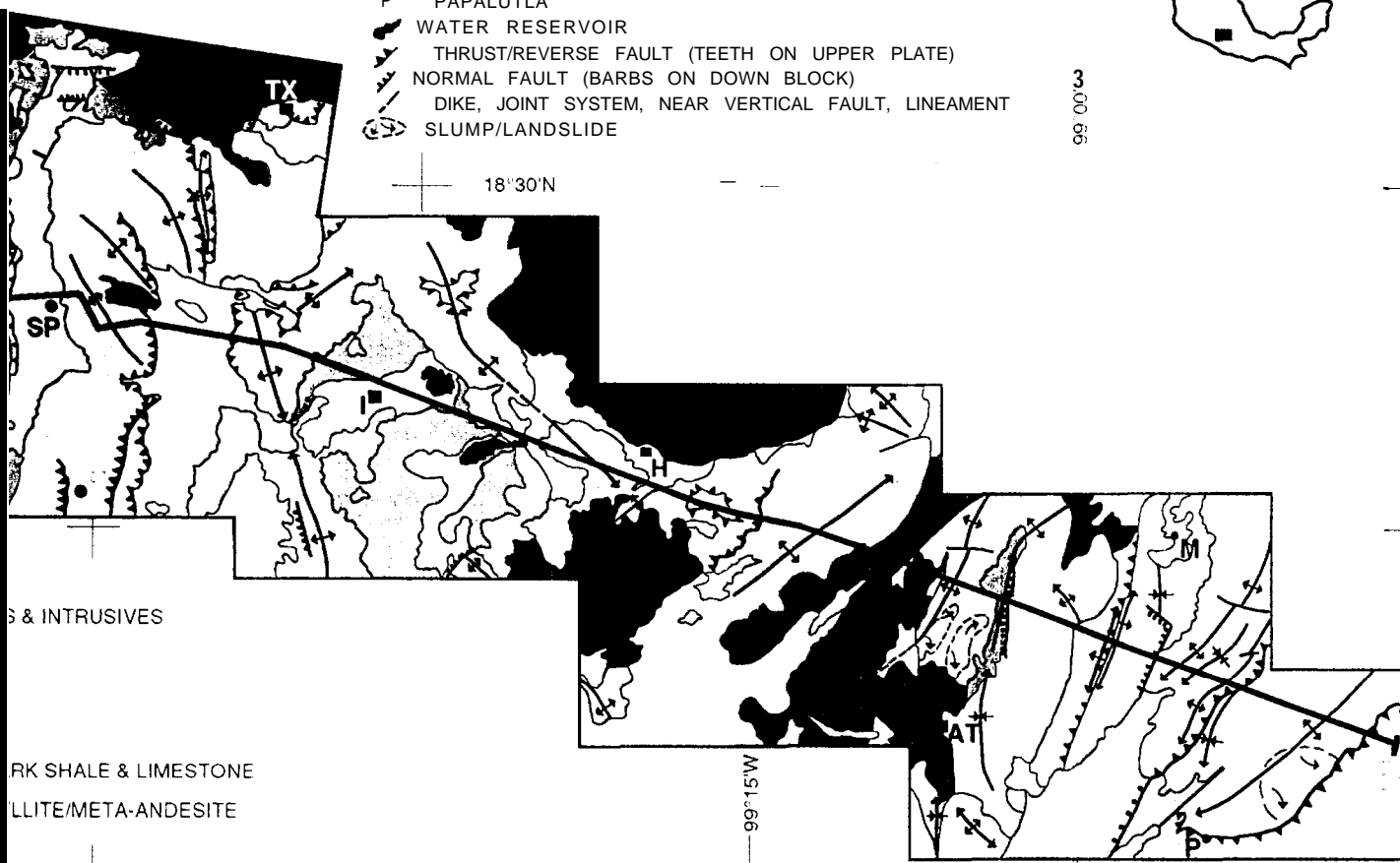


3
99°00'

18°30'N

98°45'W

99°15'W



S & INTRUSIVES

ARK SHALE & LIMESTONE
LLITE/META-ANDESITE

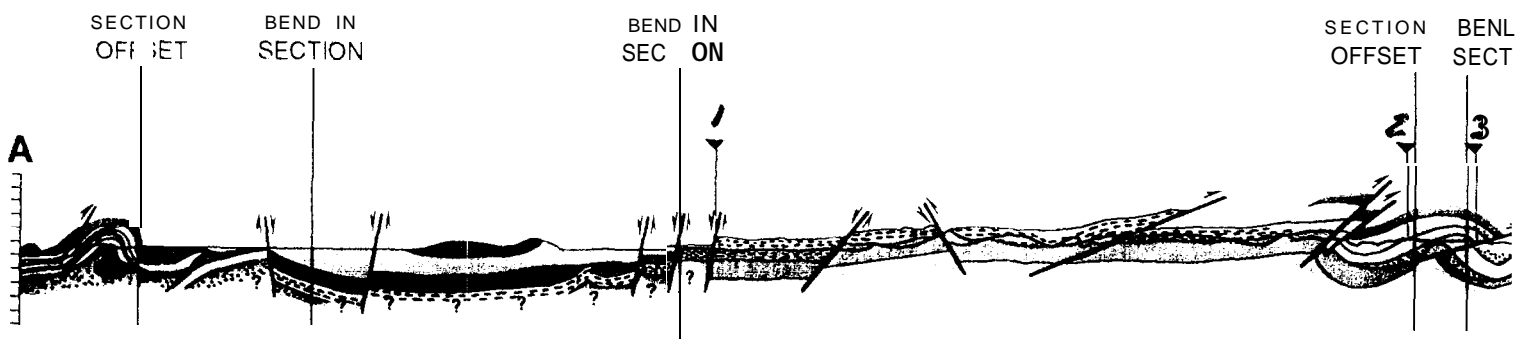


Fig 3B
Lang et al.

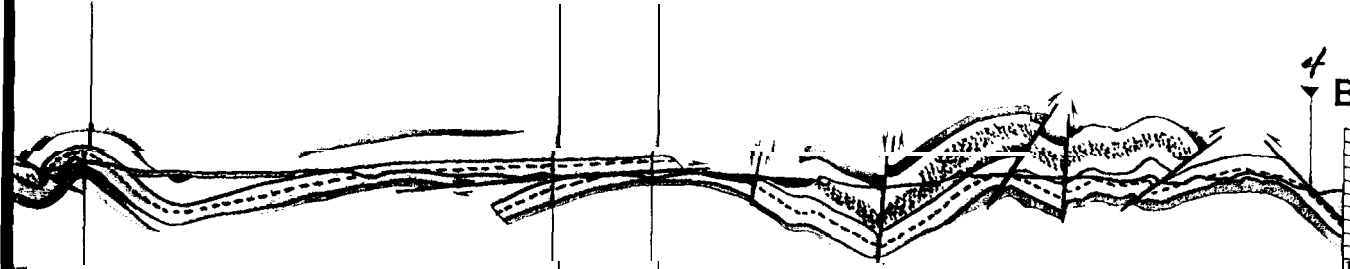
N
N BEND IN
SECTION

BEND IN
SECTION

BEND IN
SECTION

4
B

6000 m
4000 m
2000 m
SEA LEVEL
-2000 m
-4000 m
-6000 m



```

***** CLEAR LOG *****
ADD DOC ADD CLR EDIT DOC LOCATE PRINT PRINT LOG
ID Number: 17984
Author's Name: Lang First Ini: H Middle Ini: R
Srnr-code: @ Section: 323 Release: foreign Publication Type: JA
Title: Terrane Deletion in Southern Mexico

Abs/Bk/Pap: pap Stamp Date: 10/27/95 Clearance Number:
Clearance Date: Credit: Charge Number: 325-43301-0-3235
Transfer Copyright (Y/N): Transfer Date:
Reviewer:
Comments:

u
Exit If Not In Use Press Esc to Abort

```

STATUS ?

H. LANG
4-3440